

Meeting the Geospace Storm Science Challenge: Required New Science Missions Brian J. Anderson and Larry J. Paxton
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Action Required: Maintain the current SEC mission timeline and provide funding for new, key, basic science missions that address the key VSE-driven issues in geospace.

Background: The Central Role of Our Home Space Environment

The Earth's space environment, from the upper atmosphere and ionosphere, through the region of low Earth orbit, to geosynchronous orbit out to approximately lunar orbit is now recognized as a closely coupled dynamic system that displays remarkable variability with great significance for orbital dynamics, electrical charging, RF communications and navigation, and penetrating radiation damage affecting and threatening technology assets that form the backbone of human activities in space. The vital role of the Earth's space environment is recognized in NASA's Strategic Roadmap (item 10) and Focus Areas (item 9): "Explore the Sun-Earth system to understand the Sun and its effects on Earth, the solar system, and the space environmental conditions that will be experienced by human explorers."

Basic Science Drivers:

The basic science imperatives driven by our need to understand how life bearing planets like Earth sustain hospitable atmospheres protected by their planetary magnetic fields, flow directly from past NASA exploration of Earth's magnetosphere-ionosphere (M-I) system and of the magnetospheres and ionospheres of other planets in our solar system. The Earth's space environment remains the most accessible magnetosphere, astrophysical particle accelerator, and space-plasma-atmosphere interactions laboratory we have. Moreover, after studying the Jovian and Saturnian systems, the dynamics of the Earth system is now recognized as uniquely rich and varied. The extreme dynamics of the Earth-space-ionosphere system have much to teach us about planetary-space plasma interactions that we cannot learn anywhere else. Due to paucity of globally distributed observations we still do not understand what happens during geomagnetic storms and this is a fundamental gap in our understanding of planet-space interactions that we need to fill. Extreme events provide the most stringent tests of understanding and offer singular opportunities for fundamental advance. The ISTP missions and now TIMED, IMAGE, and CLUSTER have made important progress on this grand challenge problem and we now know that the M-I system is a coherent strongly coupled dynamic system.

Our understanding of space weather storms is still in its infancy – somewhat akin to our knowledge of hurricanes 50 years ago. To safely and efficiently voyage into the ocean of space we have to be as prepared the sailors of today: we have to know what space storms to design our systems to be able to withstand and we must be able to predict, with adequate warning time, when those events will occur with a high forecast accuracy.

Application of to the Vision for Space Exploration

The Earth and its space environment (thermosphere, ionosphere, inner magnetosphere) will remain the base for launching and supporting human exploration. LEO, MEO and GEO technological assets will remain key elements in the infrastructure support system (communications, solar monitoring, human presence). The entire system will only be as robust as its weakest link. The only way to ensure the security/integrity of the exploration infrastructure

is to understand the basic science of geospace and apply this understanding to developing a tiered prediction-monitoring-assimilation network based on observations and dynamic models/simulations. NASA plays a leadership role in developing the predictive capability that ensures mission safety and providing meaningful, manageable margins for the safe flight of human and robotic missions to Mars and the Moon and the construction of the assets required in space to carry out other facets of the Vision for Space Exploration.

Approach

New science missions will be required to achieve the necessary physical understanding of geospace dynamics because although existing data sets provide invaluable guidance and constraints, they also clearly indicate the new class of observations that are needed to resolve the grand challenge of the storm-time magnetosphere-ionosphere system. The new missions summarized below and not rank-ordered, would augment and extend the measurements of the current Sun-Earth Connections program. The timeline for these missions (completed in 10 years) would support the application of these measurements and our understanding of the engineering environment to the Vision for Space Exploration.

1. Radiation belt dynamics. Multi-point observations of particles, plasmas and waves in the equatorial inner magnetosphere are required to provide the necessary observational basis with which we can distinguish competing theories and models and identify the correct constellation and linkage of physical processes governing the radiation belts.
2. Ionosphere/thermosphere storm-time dynamics. We now know that we need continuous global-scale observations, including imaging of the ionosphere/thermosphere system to acquire the basic observation basis to resolve this issue.
3. Storm-time electrodynamics. The stubborn fact remains that because of the short time scales (<20 minutes) and huge spatial domain of the M-I system, we have never obtained the comprehensive global scale observations required to adequately document what the magnetosphere-ionosphere system does during geomagnetic storms. Since this objective is so important and will require constellation class observations, every opportunity needs to be explored to leverage existing missions, ground-based capabilities and partner opportunities with NOAA, DoD and private industry.
4. Magnetosphere-ionosphere coupling physics. The intrinsic dynamics of the ionosphere below 600 km altitude at high and mid-latitudes as well as the mid-altitude ($< 2 R_E$) coupling region associated with the aurora are sites where physical processes cascade from the small scale to large scale and coordinated multi-point observations are required to resolve the collective manifestation of the microphysics.
5. Magnetotail energetics and collective dynamics. The Earth's magnetotail is an astonishingly unique and dynamic physical system that governs electromagnetic energy storage and release to the nightside ionosphere and to prompt particle acceleration. The physics in the tail spans a multiplicity of scales and as with M-I coupling physics it is the cross-scale coupling that must be understood. A constellation class mission involving many simple measurements is needed.